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# CEMENT DISPERSION AND AIR ENTRAINMENT IN CONCRETE PAVEMENT CONSTRUCTION



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## FOREWORD

CONSTRUCTION of highways and other pavements presents a peculiar and difficult problem. The conditions to which such structures are exposed are particularly severe and properties not of primary importance in other work are required.

During the last ten years cement dispersion has proved its value and economy in concrete construction generally. More recently the value of incorporating added air in concrete, particularly with reference to decreased scaling and added resistance to freezing and thawing has been recognized.

A product combining these two principles has now been developed which combines the virtues of both. This paper has been written with the objective of acquainting highway engineers and others who would be interested with the nature of this product, the manner in which it functions, and the results which can be secured.

## ABSTRACT

Highway concrete differs in its requirements from concrete generally in certain respects. High transverse strengths and surfaces resistant to wear and scaling are particularly necessary.

The incorporation of more than the normal amount of entrained air in the mix contributes to greater workability, reduced bleeding, increased resistance to scaling, and improved durability. This air entrainment may be secured by use of a portland-natural cement blend, a Vinsol resin cement, or the addition of a foaming agent. Each of these has certain advantages and disadvantages.

The value of cement dispersion in concrete mixes has been established over a period of years. It is effective in improving the properties of the concrete in both the plastic and hardened states and is economical.

A material, HP-7, designed especially for highway or other pavement construction has been developed by combining the most satisfactory foaming agent with the most practical cement dispersing agent. The advantages of both are realized and the disadvantages of a foaming agent are overcome.

HP-7 is an effective means of securing those properties which have been sought from the use of portland-natural cement blends, from Vinsol resin cements, and from certain admixtures. It is, however, free from the disadvantages which these have. HP-7 may be used effectively with any type of cement or blend.

HP-7 appears to offer at least a partial solution and the most satisfactory solution so far available to the problem of securing high strength, prevention of scaling, increased durability, and improved wear resistance in pavement construction.

# RELATION OF DISPERSION TO SPECIAL CEMENTS

## Table of Contents

# CEMENT DISPERSION AND AIR ENTRAINMENT IN CONCRETE PAVEMENT CONSTRUCTION

## INTRODUCTION

THE problem of concrete for highways presents some differences from that of concrete for general structural purposes. Highways are essentially large flat slabs of comparatively small thickness which are exposed to rather severe conditions. They must be able to carry heavy loads, to stand exposure to severe weathering conditions, and must have a wear resistant surface. These are conditions not usually encountered simultaneously in ordinary construction.

The requirements of highway concrete are relatively high transverse strength to carry the loads, durability to resist attack due to exterior exposure and such added adverse conditions as de-icing with calcium chloride or salt, and avoidance of any phenomena which might impair the strength or durability of the surface. While it is usually possible to secure a satisfactory quality with respect to any one property of concrete, it is often difficult to secure a combination of properties which will be all that is desired. It is perhaps for this reason that a great deal of investigation has been directed to highway concrete without as yet reaching any agreement on a wholly satisfactory solution.

Two other properties of concrete are of some importance in highway work. Workability in this type of concrete is essential, as it is in any other. There is usually little difficulty in securing adequate workability with the mixes commonly used. Volume change is also a factor in that, if excessive, undue cracking of the slab will occur. Adequate reinforcing and proper location of joints will usually prevent excessive cracking if a mix of any reasonable volume change is used.

To secure high strength, compressive or transverse, is not in itself difficult. A mix of adequate cement content with a low water-cement ratio will be required. Further, any influence which tends to interfere with the hydration reactions or to impair the quality of the cement paste structure will be undesirable.

Durability of the concrete as a whole is also not a serious problem. A low water cement ratio is required but without unduly high cement content.* High strength and low permeability will contribute to durability. Recently there has been considerable work on the introduction of small amounts of air into concrete by various means. It appears to be fairly generally believed that a small increase in entrained air adds substantially to durability. It seems probable that excessive air entrainment is undesirable as the beneficial effects would be overcome by the loss in strength.

To secure a satisfactory surface is a more difficult problem and probably more important. In the first place the surface must have

* Lewis H. Tuthill. J.A.C.I. June, 1939, page 589.

high strength to resist abrasion, in the second, high durability to withstand the weather and treatments applied to the surface. F. H. Jackson ** of the Public Roads Administration, has summed up the situation as follows:

> "While a good deal of publicity has been given the matter of scaling in New York State, I personally have seen considerable scaling on concrete pavements in many other northern states. The scaling is, I think, undoubtedly associated with freezing and thawing and is, I believe, primarily the result of water gain or segregation during placing. This results in the formation of a thin porous layer on the top of the pavement which is an easy prey to the action of ice and salts used for ice removal. It is my opinion that the principal effect of the natural cement is to reduce the amount of this water gain, thereby producing a more uniform mix from bottom to top of the slab, and consequently a denser surface. I do not think there is anything very mysterious about it. Furthermore, there may be other materials that will accomplish the same thing."

## METHODS OF INCORPORATING AIR

A number of means have been investigated recently, both in the laboratory and by laying experimental roads for the entrainment of air to improve the quality of the highway by reducing bleeding. These include the use of blended cements, particularly portland-natural blends, the use of cements ground with various grinding aids such as rosin, beef tallow, stearates, and especially Vinsol resin, and the addition to the mix of foaming agents, especially Orvus (sodium lauryl sulphate). Each of these methods has its advantages and disadvantages.

All the foregoing methods of incorporating additional air into the mix have some effects in common. All necessarily lower the unit weight of the concrete. All reduce bleeding markedly and produce a more fatty or cohesive mix.

It seems immaterial whether the unit weight of the concrete is increased or decreased as long as this is not an index of other properties. In the case of the air-entraining methods decreased weight, at least up to a certain point, is a criterion of improved durability. Reduction in bleeding can hardly be anything but beneficial. It might be thought that increased cohesiveness or fattiness as an aspect of workability would be beneficial, but, with the methods of finishing commonly used in highway work such does not appear to be the case. The fattier mixes tend to pull and are more difficult to finish. To secure reduced bleeding, however, it seems to be necessary to increase cohesiveness.

The effects of air entrainment on bleeding are discussed by Powers* as follows:—

"Some materials, when added to a mix or when ground with the cement, cause the formation of a comparatively stable foam which gives the mix a high air content. This has a pronounced effect on the rate of bleeding through a reduction in the effective capillary area

** A.S.T.M. Proc., Vol. 38, 1938 — Discussion, page 352.

*The Bleeding of Portland Cement Paste, Mortar and Concrete—by T. C. Powers, Research Laboratory of the Portland Cement Association—Bulletin 2.

per unit gross cross-sectional area and through the effect of the buoyancy of the bubbles on the force causing bleeding. The effect of the air can be established by treating it as if it were an aggregate added to the paste, an aggregate having definite volume but negative weight.

"It will be observed that the entrained air effects very substantial reductions in the bleeding rate and that the calculated values are in good agreement with the observed except in the case of the highest air content. This latter value was checked and the discrepancy found not to be due to error. It is believed that, when the air content becomes sufficiently high, the bubbles, ceasing to act independently, tend to merge their boundary films and knit the whole mass together by means of surface tension forces. With this amount of air the paste will 'stand up' like whipped cream. It is possible also that the effect of added surface in reducing the hydraulic radius may be involved, but this seems doubtful, for examination under the microscope indicated that the bubbles were large enough to have a low specific surface. It was for this reason that the surface effect was neglected in developing the above equations.

"These tests on neat cement paste do not tell the whole story of the effect of air on bleeding as it would be experienced in practice, for in these tests the water-cement ratio was constant. In practice, the use of a foaming agent in a given mix permits a substantial reduction in the water-cement ratio because of the fluidity of the air itself. The effect of such a reduction in water, superimposed on the effects expressed by equation 36, would result in a very low bleeding rate as compared with that of the same mix made without the foaming agent. It seems therefore that this method of reducing bleeding deserves further study, especially in view of the recent tests which indicate that the introduction of a high proportion of air by means of a foaming agent greatly increases the resistance to frost action."

Each of the air entrainment methods is considered individually below.

### Natural Cement Blends

Natural cements were produced prior to the development of portland cements. In the early days portland cement was used as an admixture to natural cement concrete to improve the strength, especially at early stages. The natural cements, as the name implies, are produced from a naturally occurring "cement rock" which has a composition similar to that of the portland cement raw mix. The cementitious qualities of the "rock" are developed by burning to temperatures somewhat lower than those used for production of portland cement clinker.

In certain respects natural cements are superior to normal portland cement, although they vary widely among themselves. Because one natural cement imparts desirable properties to the concrete does not necessarily imply that some other natural cement will do likewise. The advantageous properties of natural cements are a greater degree of cohesiveness or "fattiness" which reduces bleeding and segregation, greater durability, and lower heat evolution. The chief disadvantages are slower rates of setting and hardening, lower strength, at least until after very long curing, and a higher water requirement for a given consistency.

There is no agreement on the causes for the properties of natural cements. It may be that the natural origin of the "cement rock" and the lower burning temperature produce a surface condition which favors greater water retentivity and hence fattiness. On the other hand, the properties of these cements have been attributed to the entrainment of a higher proportion of air in the mix which has been, in turn, ascribed to small amounts of oil or grease accidentally (or purposely) included in the cements during their manufacture. The observed increases in durability might be explained on the basis of reduced bleeding, which would help to prevent surface scaling, or to increased entrained air. More probably both influences are responsible. The lower heat evolution, as also the slower setting and strength development, are obviously caused by slower hydration.

### Vinsol Resin Cements

A number of materials have been used as grinding aids, that is, to reduce the amount of grinding of cement clinker to produce a cement of the required fineness or surface area. Among materials which are more or less effective are Vinsol resin, rosin, beef tallow, oil, grease and others. In addition to the function of these materials in facilitating grinding, they also affect the properties of the cement when used in concrete with respect particularly to strength, cohesiveness or fattiness, bleeding, and the entrainment of air.

The best known grinding aid of this type and one which has been used to a certain extent is Vinsol resin. It is a by-product of the naval stores industry. When portland cement clinker is ground with a very small amount of Vinsol resin (.03% is commonly used) the grinding is greatly facilitated. What is more important, to the consumer, a cement so ground tends to entrain a considerable amount of air and to be more cohesive or fatty. In these respects the Vinsol resin ground cements produce essentially the same results as a blend of natural with portland cement.

**TABLE I**

**Vinsol Resin Ground Cement**

Concrete Mix — Cement ........................ 467 lbs.
Sand ........................ 1346 lbs.
Stone — 3/4" ........................ 1988 lbs.

| Cement | Vinsol Resin | Surface Area Sq.cm./g. | w/c Gals./sk. | Slump In. | Compressive Strength Lbs. per sq. in. 3 days | 7 days | 28 days | Unit Wt. lbs./cu.ft. |
|---|---|---|---|---|---|---|---|---|
| A | None | 2090 | 7.6 | 3 | 2240 | 3220 | 4450 | 147.5 |
| A | .03% | 2125 | 7.1 | 2¾ | 2350 | 3270 | 3410 | 143.8 |
| B | None | 1920 | 7.2 | 2¾ | 3025 | 4530 | 4775 | 148.2 |
| B | .03% | 1982 | 6.8 | 3 | 2230 | 3150 | 3820 | 139.6 |
| C | None | 1665 | 7.0 | 2½ | 2790 | 3840 | 4950 | 151.0 |
| C | .03% | 1650 | 6.8 | 3 | 2085 | 3160 | 3770 | 145.5 |
| D | None | 2100 | 7.5 | 2½ | 2970 | 3440 | 4760 | 150.0 |
| D | .03% | 2090 | 7.4 | 3 | 2460 | 3250 | 3860 | 145.5 |

The Vinsol cement suffers from the same disadvantage as a portland-natural blend in that strengths are lower. This decrease in strength appears to be greater for the Vinsol resin cement than for

the blend and, moreover, it is permanent: that is, with long curing the strength of the concrete made with a portland-natural blend will probably equal that of a straight portland mix, whereas the Vinsol resin cement will always show lower than normal strengths. Apparently the loss in strength is directly related to the amount of air entrained. Some strength data on cement ground with and without Vinsol resin are given in Table No. 1. It is especially to be noted that, although the water-cement ratio is lower for the Vinsol resin cement, due to the replacement of water by entrained air, the strengths are markedly lower instead of higher as would be expected.

Another difficulty with Vinsol resin cements is that their behavior is very variable. The effect of a given percentage of Vinsol resin, as measured for example by the decrease in unit weight of the concrete which is an index of the amount of air entrained, seems to vary with different cement clinkers; even with clinker from the same mill produced at different times. This variation implies that the effectiveness of the Vinsol resin with respect to air entrainment, bleeding, segregation, fattiness, durability, and strength will vary. In the present state of our knowledge these variations are unpredictable. This means that, because a certain percentage of Vinsol resin is ground with the cement clinker, it does not necessarily follow that the desired properties will be secured. A better criterion of the effectiveness of a Vinsol resin cement would seem to be the drop in unit weight of concrete made with the cement in question compared with a similar mix from normal portland cement. This, however, seems to be a matter of trial and error from one lot of cement to another.

Vinsol resin cements have been offered and to some extent used as a substitute for portland-natural cement blend, to produce similar properties in the concrete mix, particularly increased fattiness and less tendency towards scaling. They are competitive on a cost basis, as neither adds substantially to the cost of the concrete. Considering the variability of the Vinsol resin cement and the losses in strength which may result it would seem that, if the quality of workability which either Vinsol resin cement or the portland-natural blend will impart is desired, the choice would be on the latter.

Rosin, beef tallow, oil, and similar materials are very similar to Vinsol resin. Like this last, they also impair strength. On the whole, such information as is available would indicate that they are less satisfactory than Vinsol resin and there is no evidence that they have received any general acceptance although some experimental highway installations have been made.

**Foaming Agents**

A large number of organic compounds will produce foaming. They decrease the surface tension of water and those which are highly effective in this respect are also known as wetting agents. Any material which will produce a stable foam will, when added to a concrete mix, tend to increase the amount of air entrained.

A discussion* of the general nature of wetting agents and their behavior is as follows:—

"In general, wetting agents are more or less complicated chemical molecules composed of two essential parts. One is termed 'hydro-

*From Aerosol Wetting Agents by American Cyanamid & Chemical Corp.

philic,' and it is the portion which draws the agent into water, or is attracted to surfaces which are the more polar. The other part of the molecule is termed 'hydrophobic,' and it tends to leave the water and attach itself to or dissolve in an oil or other non-polar medium. Such a molecule will orient or align itself at the interface, so that the hydrophilic part will be in the water and the hydrophobic part in the organic phase. The fundamental governing factor in such orientation is the attraction of like atoms or groups of atoms for one another.

"Wetting agents belong to a group of a more general class of materials called 'surface active agents,' and among their properties is their ability to lower surface tension and interfacial tension. Surface tension values of solutions of a wetting agent are a measure of the effective amount of the material collected at the air-solution interface; whereas interfacial tension values are a measure of the amount of material collected at the liquid-liquid interface and consequently are a measure of its surface activity.

"Surface activity is a special property and will vary from interface to interface. That is to say, because a wetting agent may be helpful in causing water to wet a hydrophobic material, it does not necessarily follow that it will be effective in promoting better wetting of a hydrophilic surface. Since conditions at the liquid-liquid interface more nearly approximate the conditions under which wetting agents are used, it is a fact that interfacial tension values are a more exact indication of wetting action than are surface tension values.

"The degree of surface activity of such an agent depends primarily upon the ratio of its hydrophilic to its hydrophobic constituents. This ratio or 'balance' is markedly affected by the nature of these antagonistic groups and by their relative position in the molecule. Advantage is taken of the factors influencing balance to formulate products suitable for specific purposes. The presence, concentration, and chemical nature of other ingredients in the system determine to a large extent the final hydrophilic-hydrophobic balance of the agent."

With respect to decreased unit weight, decreased bleeding, and increased durability, the effects of a foaming agent are essentially the same as those of a portland-natural blend, or of a Vinsol resin cement.

With respect to the other properties of the concrete, foaming agents vary widely. Many of them seem to interfere with the hydration reactions of the cement, thereby decreasing strength and possibly increasing permeability. It is possible, however, to select a foaming agent which does not impair the normal reactions of the cement and of these Orvus appears to be the most suitable.

By addition of Orvus to the concrete mix the same effects with respect to unit weight, bleeding and durability can be secured as with a portland-natural blend. Unlike the latter, strengths are not impaired and instead of increased water-cement ratio for a given consistency the required water is appreciably reduced. Further, lauryl sodium sulphate is a definite compound so that its properties remain constant as is not true of different brands of natural cement and possibly even of different lots of natural cement from the same source.

As compared with a Vinsol resin cement, addition of Orvus to the mix will have similar effects with respect to reduction of unit weight, bleeding and water requirement, and increased durability and cohesiveness. Unlike the Vinsol resin cement, it does not impair the

strength but should show some increase at all ages. Again, being a definite compound, it is not subject to the variability of Vinsol resin cements.

## CEMENT DISPERSION

The principle of cement dispersion has been fully discussed in Research Papers Nos. 35 and 36, but a brief review of this subject is included here.

When portland cement is mixed with water, the individual particles tend to gather together and stick to each other in clumps, i.e., the solid-liquid system is flocculated. This is due to lack of mutually repellent electrostatic charges on the cement particles. If a suitable dispersing agent is introduced into the mix, the clumps are broken up and the cement then acts as individual particles, i.e., is dispersed.

Dispersion of the cement produces two important effects. The water which had been trapped within the particle clumps is released to become a part of the mixing or placing water. The surface area of the cement in contact with water is greatly increased, since the particles are no longer in contact with each other. As a result of the first the amount of water required in the mix for a given consistency is less, i.e., the water-cement ratio is reduced. Since the value of the cement is dependent on a hydration reaction which is a surface phenomenon, the second effect which promotes more rapid and more complete hydration permits more efficient utilization of the cement. By the reduction in water-cement ratio and by the increase in surface area of cement available for hydration, the potential value of the cement is more completely realized.

Those properties of concrete which are dependent on the surface area of the cement and on water-cement ratio, and this includes most of them, must necessarily be improved by dispersion. These effects are realized in the concrete in both its plastic stage and subsequent to hardening.

During the plastic stage, dispersion of the cement in a given mix will produce more placeable concrete with less water, due to the release of water from the cement clumps. The fattiness of the mix is increased, while segregation and bleeding are reduced, due largely to the increased effective surface area of the cement. Volume change before hardening is markedly decreased, due in part to the lower water content and in part to the greater surface area.

A greater uniformity and freedom from gross defects of the hardened concrete may be expected from the improved properties in the plastic stage. Greater watertightness with reduced permeability and absorption are realized through the lower water content required for placing. Higher strengths and greatly increased durability with respect to both freezing and thawing and sulphate corrosion may be attributed to the lower water-cement ratio of the dispersed mix and to the increased surface area available for hydration.

Although dispersion of the cement will accomplish most of the effects of foaming agents and portland-natural blends or Vinsol resin cements including decreased bleeding, increased durability, and increased cohesiveness, it attains these results by an entirely different

means. Furthermore, it produces these effects without the disadvantageous properties of those methods which entrain large amounts of air but with other advantageous properties of its own.

Cement dispersion does not produce its effects by the incorporation of large amounts of air but by reduction of water-cement ratio and by making available for hydration or water retention a larger surface area of the cement. By using a cement dispersing agent, the unit weight of the concrete is not reduced appreciably (depending on the type of mix and method of handling a dispersed cement mix will show slightly higher or slightly lower unit weight than a comparable undispersed cement mix). Since dispersion permits a reduction in water for a given consistency, this means that in most cases there will be somewhat higher air entrainment with the dispersed cement but this is not large and is not of a magnitude comparable to the effect secured with a foaming agent.

## DISPERSING AGENTS, FOAMING AGENTS and PROTECTIVE COLLOIDS

At this point it may be well to point out the very definite differences between dispersing agents, foaming or wetting agents, and protective colloids. They might be considered in relation to any solid-liquid system, but for present purposes the discussion may be confined to water as the liquid since cement is a typical solid-water system in which the solid reacts with the liquid.

A dispersing agent is a compound which, presumably by adsorption in an oriented manner, causes the particles of the solid in suspension in the liquid to become mutually repellent, presumably because they are thereby endowed with like electrostatic charges at the surface. Dispersing agents are specific: that is, a compound which is a dispersing agent for one solid-liquid system may or may not be a dispersing agent for some other system. Dispersing agents may or may not lower or raise surface tension. They may or may not cause foaming. The most satisfactory dispersing agent for cement in water has a small but not marked effect in decreasing surface tension and does not cause formation of stable foams. Dispersing agents, used in the proportions suitable for dispersing cement in water, do not interfere with the hydration reactions of the cement.

Foaming or wetting agents greatly lower the surface tension of water. They form stable foams. They are not dispersing agents for cement in water. Used in moderate quantities to produce air entrainment, at least some of them do not interfere with the hydration reactions of the cement; others probably do. One case is known of a foaming agent which is also a cement dispersing agent, but this would seem to be a fortuitous combination as there is no necessary relation between these two actions.

The difference between the action of a cement dispersing agent and a foaming or wetting agent in water is illustrated in Fig. I.

Protective colloids will stabilize a suspension of a solid in a liquid, that is, the protective colloid will be adsorbed on the solid particles, preventing these from coming in close contact and hence preventing to some extent coalescence. A protective colloid will stabilize a solid-liquid system in which the solid is already dispersed by a dispersing agent or other means. In a flocculated system the protective colloid

Fig. I


← *In tube containing the foaming agent, note formation of a stable foam, which is absent in tube containing the dispersing agent.* →
*In this manner the foaming agent introduces a large quantity of air into the mix.*
FOAMING AGENT
DISPERSING AGENT

will stabilize the system in the flocculated condition. Protective colloids do not have any large effect on surface tension and are not generally dispersing agents. Therefore, a protective colloid added to a cement-water system does not produce dispersion. Some particular protective colloid may also be a cement dispersing agent but this is rare and is perhaps better stated that some dispersing agents for cement may also be protective colloids. Protective colloids are not in themselves active foaming agents but they do tend to stabilize foams. The adsorption of a layer of protective colloid on the surface of the cement particles appears to interfere with hydration.

A suspension of cement in water may be termed a rather gross colloidal system. Only a small portion of the cement particles of smallest size are really of colloidal dimensions and will stay suspended indefinitely. The effects of dispersing agents, wetting agents, and protective colloids are therefore less marked and less clear cut than they would be in a truly colloidal system. This is a matter of degree rather than of the nature of the phenomena. The finer the cement is ground the more closely its behavior will resemble that of a true colloidal system and for this reason the effects of a dispersing agent are more marked with a fine cement.

It is also true that as commonly used in a concrete or mortar mix the cement and water are in such proportions that they form a paste rather than the dilute suspensions usually employed for the study of colloidal phenomena. The solid particles no longer move as freely in the liquid medium. There is, however, no doubt that the same phenomena occur, although they may manifest themselves in a somewhat different manner. For example, dispersion has a marked effect in lowering the viscosity of a suspension of a solid in water having in the flocculated condition a viscosity appreciably higher than that of water. As the suspension becomes more dilute and in any condition, flocculated or dispersed, approaches the viscosity of water, this effect becomes less marked and as the suspension becomes more concentrated and higher in viscosity it becomes more pronounced. These are well known effects which have been observed in clay and other suspensions and put to practical application in casting with clay slips and in similar processes. In such solid-liquid systems the relation between dispersion, viscosity and adsorption can be followed through alternate cycles of flocculation and dispersion. Similar phenomena are exhibited by suspensions of cement in water of paste consistency.

## DEVELOPMENT OF HP-7

The benefits to concrete of cement dispersion have been established in this and other laboratories and in the field during a development which has extended over more than ten years. The advantages derived through the application of this principle to the properties of concrete generally have been described elsewhere (Research Paper No. 35) as has also its economic value (Research Paper No. 36). These advantages are equally applicable to highway concrete generally, but there remained the possibility that, to fit the special requirements of highway work, other principles could be applied which would more nearly approach a solution of this special problem.

Within recent years the desirability of incorporating somewhat more air in concrete than is ordinarily entrained has been investigated in this and other laboratories. Now there appears to be little question that certain benefits are secured by this means as described above. Certain of the highway departments have pursued this subject somewhat further as has also the Portland Cement Association and a number of experimental roads have been laid using what may be called air incorporating agents. The most satisfactory such material seems to be Orvus (sodium lauryl sulphate) and at least one highway department has definitely reported that observations from a comparison of a number of experimental road sections have indicated that this is the case.

The introduction of air into the cement paste is undoubtedly attended by undesirable effects, whether or not the benefits of so doing outweigh the disadvantages. It appeared that a combination of the principle of dispersion with that of air incorporation might solve these difficulties. By dispersion of the cement it should be possible to overcome the deleterious effects of air incorporation and to superimpose the benefits of cement dispersion.

From these considerations HP-7 was developed. It is essentially a combination of the best air incorporating agent, sodium lauryl sulphate, with the most satisfactory and economical cement dispersing agent, a derivative of lignin sulphonic acid.

## EFFECTS OF HP-7

As would be expected from its composition, HP-7 produces two effects, that of a dispersing agent and that of a foaming agent.

The effects of a dispersing agent on a concrete mix are those which have been described elsewhere. They are essentially as follows:—

A. *In the plastic state of the concrete:—*

1. More placeable concrete with less water
2. Increased fattiness
3. Reduced segregation and bleeding
4. Greater water retentivity
5. Reduced shrinkage before hardening

B. *In the hardened concrete:—*

1. Increased durability
2. Increased watertightness
3. Higher strength
4. Lower volume change
5. Lower permeability and absorption
6. Greater uniformity and freedom from gross defects

The effects of the introduction of additional air by means of a foaming agent are essentially as follows:—

A. *In the plastic state of the concrete:—*

1. Increased fattiness
2. Reduced bleeding

B. *In the hardened concrete:—*

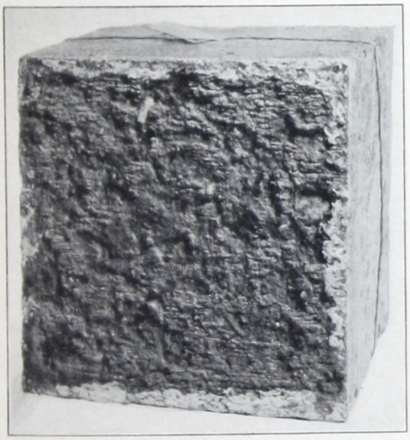
1. Increased durability
2. Greater uniformity and freedom from gross defects.
3. Strength unaffected by a suitable foaming agent but reduced by others.

With respect to fattiness and bleeding, the dispersing agent and the foaming agent reinforce each other. The same is true of durability and uniformity of the concrete. The dispersing agent overcomes any tendency of the foaming agent to lower strengths by diluting the cement paste with air and actually produces increases in strength.

As a consequence HP-7 attacks the problem of improving highway concrete at those points which have, in the past, been the most vulnerable. The effect on durability and bleeding is illustrated by the results of freezing and thawing (with calcium chloride) tests shown in Fig. II. The effects on strength are shown in Table II. It is hardly possible to express fattiness or freedom from gross defects quantitatively but there can be little doubt, as has been shown by numerous qualitative observations by many different observers, that HP-7 does markedly improve these properties.

Fig. II

Effects of Freezing and Thawing (with calcium chloride) on the surfaces of slabs. The same concrete mix at the same slump was used in each case.



Plain

With HP-7

**TABLE II**
**TEST RESULTS**

| Addition | Lbs. Water | In. Slump | Compressive Strength Lbs. per sq. in. 3 days | 7 days | 28 days | Gals. per Sack |
|---|---|---|---|---|---|---|
| None | 21.56 | 2½ | 1420 | 2140 | 3410 | 8.0 |
| HP-7 1#/sk | 18.44 | 3 | 1770 | 3090 | 4080 | 6.9 |
| None | 21.31 | 2¾ | 1560 | 2350 | 3290 | 8.0 |
| HP-7 1#/sk | 17.63 | 2¾ | 1840 | 2550 | 3670 | 6.6 |
| None | 21.69 | 2½ | 1310 | 2020 | 2940 | 8.15 |
| HP-7 1#/sk | 17.88 | 2½ | 1880 | 2850 | 3700 | 6.75 |

Concrete Mix— — Cement (Portland) ........... 30 lbs.
Sand ........................ 90 lbs.
Stone (¾″) ................ 133 lbs.

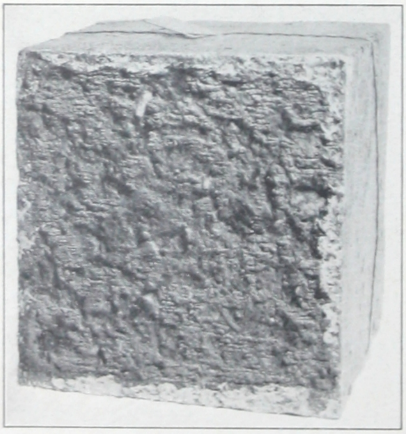
## ECONOMICS OF HP-7

The actual cost of the materials which compose the concrete mix used for highway concrete is undoubtedly only a very small portion of the total cost of highway construction. The cost of any material which had even a small influence in prolonging the life of the concrete and which caused only a small percentage increase in the cost of these materials would be amply justified. The increase involved in adding HP-7 to an ordinary highway mix would amount to about 5% of the cost of the materials and this might be estimated as amounting to not more than 0.1% of the total cost of the highway. If even a 1% increase in the life of the concrete were secured by this means, the expenditure would be well warranted.

This is not, however, the situation. Life of the concrete is increased to a vastly greater extent and this increase can be secured at no additional cost. The cost of adding HP-7 to the average highway concrete mix amounts to about the equivalent of the addition of ½ additional sack of cement. The greatly increased durability of a mix with HP-7, costing approximately the same as a similar mix without HP-7, is illustrated in Fig. III.

Fig. III

Effects of Freezing and Thawing (with calcium chloride) on the surfaces of slabs. The plain mix is at the same consistency as the mix with HP-7 but contains ½ sack additional cement per cubic yard.



PLAIN

WITH HP-7

With respect to the other properties of these two mixes, the strength is not decreased but increased (Table III). Permeability and adsorption are decreased. Volume change is reduced. Segregation, shrinkage before hardening, are decreased. Uniformity, watertightness, water retentivity, and placeability are increased.

This means essentially that, at a given cost, the quality of the concrete is improved by the incorporation of HP-7 and that as a consequence a highway of longer life with greater freedom from scaling is secured at no additional expense.

## TABLE III

| SERIES I | Lbs. | In. | Compressive Strength Lbs. per sq. in. | | | Gals. per |
|---|---|---|---|---|---|---|
| *Addition* | Water | Slump | 3 days | 7 days | 28 days | Sack |
| None | 21.56 | 2½ | 1420 | 2140 | 3410 | 8.0 |
| HP-7 1 # /sk — 10% less cement | 18.31 | 2¾ | 1450 | 2460 | 3360 | 7.65 |
| SERIES II | | | | | | |
| *Addition* | | | | | | |
| None | 21.31 | 2¾ | 1560 | 2350 | 3290 | 8.0 |
| HP-7 1 # /sk — 10% less cement | 17.38 | 2¾ | 1730 | 2520 | 3610 | 7.25 |
| SERIES IV | | | | | | |
| *Addition* | | | | | | |
| None | 21.69 | 2½ | 1310 | 2020 | 2940 | 8.15 |
| HP-7 1 # /sk — 10% less cement | 17.56 | 2½ | 1730 | 2570 | 3560 | 7.35 |
| HP-7 1 # /sk — 13% less cement | 17.56 | 3 | 1290 | 2000 | 2970 | 7.65 |

Concrete Mix — Cement (Portland)............... 30 lbs.
Sand.......................... 90 lbs.
Stone (¾")....................133 lbs.

| | Normal Portland Cement Plain | HP-7 |
|---|---|---|
| Cement — lbs. | 574 | 499 |
| Sand — lbs. | 1134 | 1123 |
| Gravel — lbs. | 2099 | 2070 |
| Water — gals. | 31.2 | 28.2 |
| Slump — in. | 1⅞ | 2¼ |
| Compressive Strength— Lbs. per sq. in. | | |
| 3 days | 2630 | 2250 |
| 7 days | 2790 | 2910 |
| 28 days | 3430 | 3750 |

## RELATION OF HP-7 TO SPECIAL CEMENTS

The only special cements which have been proposed for highway work are the portland-natural blends and cements ground with a grinding aid such as Vinsol resin. The effects of these have been described above.

HP-7 will produce similar effects to those of portland-natural cement blends and will further give results not obtained with these. With HP-7 the increased water-cement ratios of natural cement blends for a given consistency are not required but decreases are secured. The early strengths are not impaired but increased. The variability encountered with different natural cements is not encountered and a definite controlled result is produced.

In addition the desirable properties which spring from a decreased water-cement ratio such as lower volume change, increased strength, and increased watertightness are realized. There would seem to be no question that, for a given result, the more desirable means of securing it, as compared with a portland-natural blend, would be the use of HP-7.

There is, however, another way of looking at this question. Natural cement blends undoubtedly have beneficial effects on highway concrete which seem to outweigh their disadvantages. It may seem desirable to use such a blend. In this case HP-7 will have the same advantages in a portland-natural blend as it will have in a straight portland cement mix. Strengths will be equal or greater (Table IV), bleeding will be further reduced and durability increased, (Fig. IV). Here also volume change will be decreased, watertightness and other properties improved.

**TABLE IV**

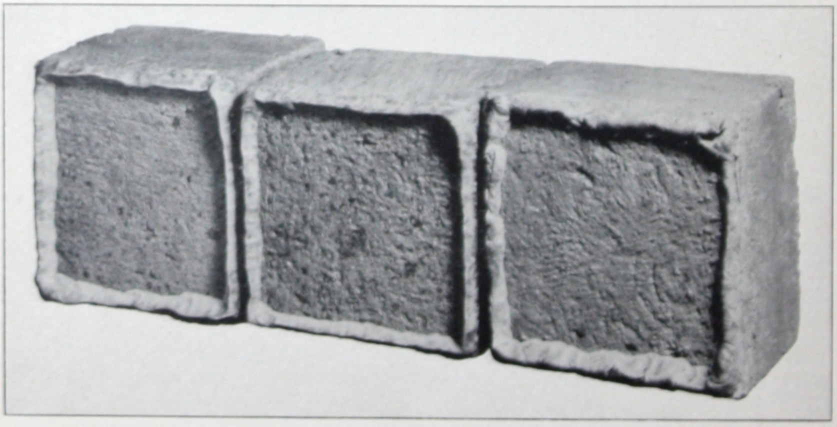
| | Blend – Portland 83½% – Natural 16½% | |
|---|---|---|
| | Plain | HP-7 |
| Cement — lbs. | 562 | 503 |
| Sand — lbs. | 1110 | 1132 |
| Gravel — lbs. | 2056 | 2085 |
| Water — gals. | 32.9 | 29.4 |
| Slump — in. | 1⅞ | 1⅞ |
| Compressive Strength, Lbs. per sq. in. | | |
| 3 days | 1970 | 2075 |
| 7 days | 2310 | 2750 |
| 28 days | 2760 | 3320 |
| Transverse Strength, Lbs. per sq. in. | | |
| 12 days | 525 | 580 |
| 28 days | 556 | 590 |

Fig. IV

Effects of Freezing and Thawing (with calcium chloride) on the surfaces of slabs of:

A. Portland Cement Concrete — plain
B. Portland Cement Concrete — with HP-7
C. Natural-Portland Blend — plain

All mixes are of the same design and at equal consistency (slump).

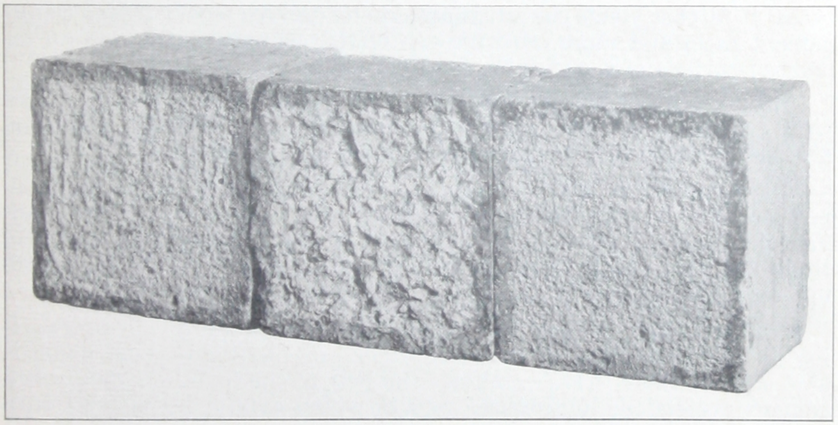


B. Portland Cement with HP-7 A. Portland Cement plain C. Natural-Portland Blend - plain

In comparison with Vinsol resin cements, the situation is much the same (Fig. V). The same effects can be produced at the same or less cost. Further, other properties such as volume change, watertightness, and so forth, are improved. The Vinsol resin and similar cements usually show losses in strength if they are effective in incorporating air. If they are not effective in this respect they are useless. HP-7 shows increases in strength, consequently, for a given strength, compressive or transverse, a concrete mix with HP-7 can be produced at definitely lower cost. It should not be overlooked that for highways transverse strength is an important factor in view of the loads which highways are required to carry.

Fig. V

Effects of Freezing and Thawing (with calcium chloride) on the surfaces of slabs. All mixes are of the same design and at the same consistency. All the cements are made from the same clinker and have equal surface area (1660 sq. cm. per g).



| | | |
|---|---|---|
| Cement with HP-7, compressive strength at 28 days, 4630 lbs. per sq. in. | Normal Portland Cement, compressive strength at 28 days, 3210 lbs. per sq. in. | Cement ground with .032 Vinsol Resin, compressive strength at 28 days, 2660 lbs. per sq. in. |

Again, from the other point of view, HP-7 can be used in conjunction with a Vinsol resin cement or similar cement to produce the desired properties in a higher degree and at lower cost. In this case, however, care should be taken to design the mix in such manner that an excess of air is not introduced.

## RELATION OF HP-7 TO ADMIXTURES

The part played by admixtures has been discussed at some length in Research Paper No. 38. As far as highway construction is concerned the only admixtures which might be of interest are those foaming agents which incorporate additional air.

(In some cases high early strength is a factor so that calcium chloride might be considered as also high early strength cement and additional cement. These topics in their relation to cement dispersion are discussed in Research Paper Nos. 36, 37 and 38.)

The foaming agents undoubtedly offer some advantages with respect to air inclusion as it improves durability and reduces bleeding. This has been discussed above. HP-7 includes a suitable proportion of the most satisfactory foaming agent. In addition it applies the principle of cement dispersion to highway concrete, thereby overcoming the disadvantages of foaming agents alone and adding the benefits of cement dispersion.

## SUMMARY

HP-7 is a combination of those two principles which seem to offer the greatest chance of solving the problem of durable wear resistant highways. The employment of a foaming agent causes increased air incorporation and thereby increases fattiness, durability, and resistance to scaling and decreases bleeding. The application of cement dispersion offsets the disadvantages of a foaming agent such as diminished strength, increased volume change and possibly increased water-cement ratio. It further yields the advantages to be derived from reduced water-cement ratio and more effective use of the cement by making an increased surface area available for hydration.

Economically, the use of HP-7, by designing the concrete mix with this material, permits all the advantages of cement dispersion and air incorporation to be secured at no additional cost.

In comparison with certain special cements such as natural-portland blends, or grinding-aid (Vinsol resin) cements, the same advantages may be secured at lower cost without the disadvantages of these cements. With these special cements themselves, HP-7 secures not only the benefits of the special cements but adds to them.*

Admixtures in general do not produce the results of HP-7. Foaming agents offer some of its advantages but have also some undesirable effects. Since HP-7 combines the best of the foaming agents with cement dispersion, it produces results which cannot be secured with admixtures generally and moreover at substantially lower costs.

* With these special cements it is possible that a cement dispersing agent without foaming agent could be used to greater advantage than HP-7.

## TEST PROCEDURE

In order to determine the real value of HP-7 it is necessary to carry out a testing program to show its effects on the properties of the concrete and its economic value. For this purpose the following program is suggested.

First select the most satisfactory mix which it is possible to design from the materials available and using whatever cement seems most advantageous. Then proceed as follows:—

A. *Workability and Water Cement Ratio* —

With selected mix make mixes and determine slump (and flow if desired) with and without HP-7 at equal w/c.

B. *Strength* —

With selected mix make concrete mixes at equal slump (or flow) as follows:—

1. Selected mix — plain
2. Selected mix with HP-7
3. Selected mix less 10% cement with HP-7.

Make cylinders for compressive strength determinations at suitable ages (7 and 28 days), making not less than three specimens for each age. Make beam specimens for transverse strength if desired.

C. *Durability*—

(a) Make block specimens from same mixes as under B, 10″ x 10″ by not less than 5″. Cure for 28 days and subject to freezing and thawing with calcium chloride. For this purpose build dike around edges of specimens with caulking compound, putty or other suitable material. Cover with water and freeze, remove from freezing chamber and thaw with fixed amount of calcium chloride. Repeat this cycle until appreciable deterioration of surface on plain mix is observed.

(b) Make cylinder or beam specimens from same mixes as under B. Cure 28 days. Subject to freezing and thawing in saturated condition. Determine deterioration at suitable intervals by loss in weight, expansion or sonic method.

D. *Watertightness*—

Make specimens from mixes as under B, cubes, blocks, cylinders, or cut specimens from test pieces made under B. After 28 days curing allow to dry out in air. Weigh. Immerse in water and determine weight at suitable time intervals until constant weight is reached.

E. *Wear Resistance*—

Make block specimens as in C-a from same mixes as given under B. Make these specimens with smooth trowel finish. Test for resistance to abrasion by any accepted method. (A good method for testing abrasion resistance rapidly is described in the Journal of the American Concrete Institute, Sept.–Oct., 1937, page 17.)

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